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Optimization of Water-based Drilling Fluid using Non-ionic and Anionic Surfactant Additives

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Abstract

Drilling fluid with better rheological and filtration properties control are required to optimise the performance of oil well drilling. In this study, a non-ionic and anionic surfactant was used as an additive in water-based drilling fluid to optimize their rheological and filtration properties. The rheology of water-based drilling fluid was taken after being hot rolled for 16 hours at 250°F and 275°F, while the filtration tests were conducted at temperatures up to 300°F. It was found that non-ionic and anionic surfactant in water-based drilling fluid improved rheological and filtration properties. Moreover, surfactant additives are 41.3% more effective in reducing the filtration loss compared to the mud without surfactants. The long chain of non-ionic and ionic surfactant might result in a more viscous fluid, blocking the pores and forming a tight filter cake. The surfactants also caused water-based drilling fluids become more resistant at the higher temperature as shown by improved and stabilised the rheology and filtration properties after the hot aging process.

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Keywords: water-based mud; drilling fluid rheology; anionic surfactant; non-ionic surfactant

1. Introduction

In the drilling operation, the process of designing drilling fluids is very critical and becoming one of the main focus [1]. The main function of drilling fluids includes: to carry cuttings from the wellbore to the surface, to provide

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the right mud weight in order to control the formation pressure, to lubricate and to cool the drill bits and casing and to support the weight of the drill bit and the drill pipe [2], [3]. In order to obtain its best performance, optimizing the physical properties of drilling fluid that suitable at different types of field needed is very important [4].

According to their basic material, drilling fluids are classified into two type; water-based mud, and oil-based mud. Water-based drilling fluid is surely the most popular drilling mud in oil and gas exploration, due to its cheap in cost and relatively more environmentally friendly than oil-based drilling fluid [5]. However, water-based mud is also known its poor rheological and filtration properties at high temperature and other severe conditions [6], [7].

The surfactant has been used as an additive as they are good in reducing the rheology, risk of water blockage and filtrate volume that loss into the formation [7–9]. Some types of surfactants might also be used as a lubricant and prevent the formation of insitu water/oil emulsion [10], [11].

In this paper, non-ionic and anionic surfactants were employed as additives in water-based drilling fluid to optimize the rheological and filtration properties at hot rolling temperature up to 300^{o}F. 2-hexadecyloxyethnol was used as non-ionic surfactant, while alkyl benzene sulphonate served as anionic surfactant. The non-ionic surfactant has excellent wetting and emulsifying properties by nature and is biodegradable and environmentally friendly as well [9]. The mud properties measured include plastic viscosity, yield point, gel strengths and filtration characteristic.

2. Materials and Methods

2.1. Water-based Mud

For the purpose of this study, water-based mud was made by mixing these additives: water as the base fluid, clay and solids as viscosifiers, barite as the weighting agent, and surfactant. The formulation and mixing order of each mud are presented in Table 1.The muds were prepared by high-speed mixing using a Hamilton mixer at 6000rpm for 45 minutes.

Table 1. Mud formulation in the presence of surfactant

Products	DF-1	DF-2	DF-3
Water	318.74	315.38	315.38
Bentonite	17.50	17.50	17.50
Soda ash	0.25	0.25	0.25
Caustic soda	0.25	0.25	0.25
KCl	10.70	10.70	10.70
Hydrozan	1.00	1.00	1.00
Hydro PAC LV	3.00	3.00	3.00
Surfactant non-ionic	-	3.50	-
Surfactant Anionic	-	-	3.50
Barite	68.72	68.59	68.59
Density	1.2	1.2	1.2

2.2. Surfactants

The surfactants chosen in this study were previously employed as the chemical surfactant for Enhanced Oil Recovery (EOR) purposes. In this experiment, 2-hexadecyloxyethnol was used as non-ionic surfactant, while alkyl benzene sulphonate served as anionic surfactant. It was found previously that these surfactants had excellent performancein increasing the oil production. These surfactants were used in this study as an additive to optimize the mud performance.

2.3. Rheological properties

The procedure used in measuring the rheological properties was based on American Petroleum Institute (API) [12]. The rheological properties, which include plastic viscosity (PV) and yield point (YP) were measured by FANN VG viscometer which was equipped with a heating jacket to control the temperature. From the readings, the relationship between shear rate and share stress can be obtained [13]. Shear rate (1), PV (2) and YP (3) are calculated by the equations below:

$$\text{Shear rate } (s^{-1}) = \text{rpm} \times 1.7034 \quad (1)$$
$$\text{PV (cP)} = 600 \text{ rpm} - 300 \text{ rpm reading} \quad (2)$$
$$\text{YP (lb/100 ft2)} = (300 \text{ rpm reading}) - (\text{plastic viscosity}) \quad (3)$$

The rheological properties of the mud were taken after two different aging temperature applied, since the viscosity of the mud is more of a function of temperature than pressure. The temperature difference might illustrate the elevated temperature at bottom hole.

2.4. Determination of gel strength of the Mud

The definition of gel strength is the minimum shear stress needed to initiate the movement of developed gel after being undisturbed for the specific time interval. Two reading are taken both immediately after agitation of the mud in the cup for 10 seconds and after the mud in the cup had rested for 10 min [14]. The readings of these two points were then compared to see if the mud has progressive or flat gel strengths over time.

2.5. Filtration loss

The filtrate volume was measured to determine the filtration characteristic of the mud. API fluid loss apparatus was used at ambient temperature. The filtrate was collected in 30 minutes time (ΔP = 100 psi, no. 5 Whatman filter paper). The volume of filtrate loss was recorded from the graduated cylinder at the end of 30 minutes [14].

3. Result and discussion

3.1. Rheological properties

The mud rheology must be controlled at sufficient values to provide the optimum performances. The properties consist of viscosity and gel strength. Measuring and designing these properties is beneficial in producing a good mud to remove the cuttings, hold cuttings and weight material in suspension when not circulating, reduce to a minimum any adverse effect upon the well bore, and release cuttings at the surface [4].

3.2. Plastic viscosity (PV)

After being dynamic aged for 16 hours at both 250°F and 275°F, the properties of the mud were taken. The PV of the base mud DF-1 is 23 cP, while the PV of muds with surfactants, DF-2 and DF-3 were increased. The results are presented in Table 2. It can be seen from the table that the viscosity of the WBM increased slightly when the surfactants are added to the mud at the temperature of 275°F. This might be due to the surfactants used creating long molecule chains that lead to an increase in mud total viscosity. Moreover, the long chain of surfactant might cause the mud become more viscous. At the same concentration, additives with short chain molecule would not cause any increment in viscosity. However, the increment was only in small values that did not make the mud undesirably thicker by any means.

Increasing the aging temperature to 275°F caused a significant decrease in the PV of all muds, including ones with surfactants. This major change in rheology might not be preferable in drilling mud after hot rolling. Drilling fluid is designed to have a specific PV in order to carry drilled cuttings. As of this case, we might estimate that the

WBM, if after the addition of the surfactant, could not stand in high temperature at 275°F. Since the PV of the mud is strongly affected by the solids and clay available in the mud to build the viscosity, the PV dropped might be due to an incompatibility of solids used for such high temperature.

Table 2. The rheological properties improvement of water-based mud in the presence of surfactant

Samples	Aging temperature	Plastic Viscosity (cP)	Yield Point (lb/100 ft^2)	Gel Strength 10 sec (lb/100 ft^2)	Gel Strength 10 min (lb/100 ft^2)
DF-1	Before aging	23	27	8	24
(blank)	After aging 250°F	16	11	5	18
	After aging 275°F	8	4	3	13
DF-2	Before aging	24	28	8	22
(non-ionic)	After aging 250°F	17	19	7	19
	After aging 275°F	12	14	6	18
DF-3	Before aging	24	32	10	26
(anionic)	After aging 250°F	16	16	6	18
	After aging 275°F	11	9	5	15

3.3. Yield Point (YP)

The measurement of YP is important as it reflects the attraction of electro-chemical particles in the mud. When the YP appears high, that might mean there is strong attraction between the charged particles. It can be seen in Table 2 that the YP of DF-1, DF-2 and DF-3 are 27, 28 and 32 lb/100ft^2 respectively. The YP of DF-1 is clearly lower than the muds with surfactant added. Generally, the addition of surfactants increase the YP both before and after hot rolling. This reading might indicate that the YP is affected by the chemical additives presence, which are the anionic and non-ionic surfactants.

Sufficient YP is needed in the drilling fluid in order to ensure the hole cleaning process run well. From the results, it can be seen that the YP of the mud had been improved with the addition of surfactants after aging at 250°F. The addition of surfactants, both anionic and anionic (DF-2 and DF-3), increased the YP of the mud when compared to the formulation without surfactant (DF-1). The low YP of DF-1 might be due to the particles becoming push away one another which reduce the YP [15].

As discussed earlier about the WBM being not stable at aging temperature of 275°F, it is clear that DF-1 could not maintain YP after aging at 275°F. The value dropped from 27 lb/100ft^2 to 4 lb/100ft^2. When the YP dropped as happened to DF-1, the drilled cuttings would settle and accumulated in the bottom of reservoir and might cause stuck pipe. On the other hand, the YP was not severely decreased when the addition of surfactant. DF-2 and DF-3 managed to produce a sufficient YP at 275°F which is the similar value with the YP of DF-1 at lower temperature of 250°F. Hence, it can be suggested that both non-ionic and anionic surfactants improved the YP of the mud after hot rolling.

3.4. Gel Strengths

From the readings in Table 2, it was found that the surfactant additive create minimum effect to the gel strengths. The gel strengths mainly depend on the colloidal clays concentration in the mud system, similar to YP. However, sufficient gel strengths have been achieved for all muds. Although the value of gel strength needs to be sufficient to suspend and transport the cuttings, too high gels are also not desirable. When the mud is too thick, the separation of cuttings might be delayed. The 10 sec gel strength of all muds are quite similar, where DF-1 (mud without surfactant) reached 8 lb/100$ft^{2,}$ while PY-2 and PY-3 obtained 8 and 10 lb/100ft^2 respectively. It is also noticed that gels decrease when the temperature increases.

3.5. The relationship of temperature and rheology

Increasing the temperature from 250°F to 275°F caused the decrease in YP and PV. In Table 2, the PV and the YP of the mud without surfatant are compared to drilling fluid after additional 1% of non-ionic and anionic surfactant. It is learnt that hot rolling with increasing temperature from 250°F to 275°F decreased the PV and the YP of the mud significantly. Higher aging temperature on the dispersed suspensions of the mud might reduce the strength of particles bonds by thermal energy [15]. In addition of surfactants, the PV and YP of WBM reduced insignificantly, compared to the mud without surfactants (Table 2). It may be due to the performance of surfactant is quite efficient and improved the stability of the mud towards high temperatures. The data also suggest the surfactant molecule improve mud thermal resistance, hence protect the flowing behaviour.

Table 3. Filtration loss control of surfactant for water-based mud

Mud	Filtration test	Filtrate (cc/30 min)
DF-1	API	5
(blank)	HTHP 275 F	15
	HTHP 300 F	75
DF-2	API	4.5
(non-ionic)	HTHP 275 F	14
	HTHP 300 F	58.6
DF-3	API	4.4
(anionic)	HTHP 275 F	14
	HTHP 300 F	44

3.6. Fluidloss

The texture of mud filter cake is one of the parameters to be concerned in evaluating drilling fluids. It can estimate the filtration loss during drilling process. Drilling fluid component influence the filter cake characteristic [16]. It was observed that the filter cakes of mud with surfactant were more compact and thin compared to the mud without surfactant. This might be due to surfactant from long molecule chains that make the fluid more viscous and forming a tight filter cake [15]. In table 3 and Fig 2, it is shown that the addition of surfactants has successfully reduced the filtration loss 12% at ambient temperature, 6.7% at temperature of 275°F and reduces 41.3% better than WBM without surfactant at temperature of 300°F. It appears that the anionic surfactant performed more efficient than the non-ionic one. Nonetheless, surfactant shows potential to be a filtration agent for WBM.

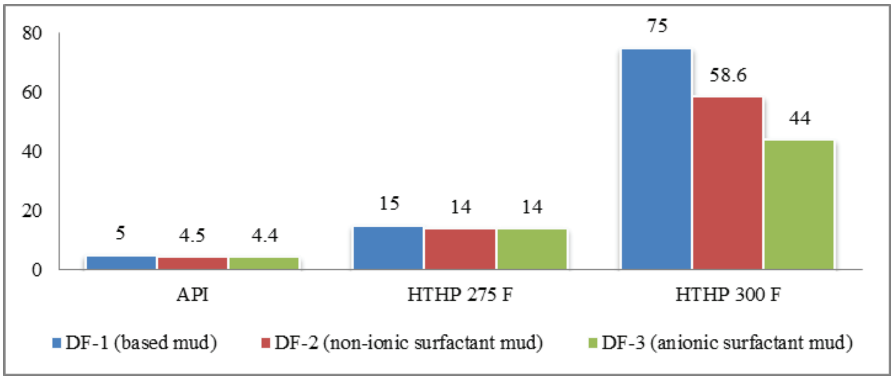

Fig. 1. Filtration test for water-based mud with and without surfactant

4. Conclusions

The results showed that the viscosity of WBM increased with the addition of surfactants, especially in terms of YP. Surfactants successfully increased the mud resistance at high temperature up to 275°F as shown by improved and stabilised their rheology after aging process. The PV and YP of WBM had also been improved with the addition of surfactants. Furthermore, gel strengths of the mud were more stable in normal and high temperature condition. Surfactant additive also decreases the amount of filtration loss up to 41.3 %, compared to the mud without surfactant. Lastly, it can be concluded that both anionic and non-ionic surfactants improved the overall performance of WBM.

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